(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 567 063 A2**

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **93106374.7**

(22) Date of filing: **20.04.93**

(51) Int. Cl.5: **H01L 21/311**, H01L 41/24

(30) Priority: **20.04.92 US 870988**
20.04.92 US 871862
20.04.92 US 871863
20.04.92 US 872701
20.04.92 US 872702

(43) Date of publication of application:
27.10.93 Bulletin 93/43

(84) Designated Contracting States:
DE FR GB IT

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(54) Anisotropic metal oxide etch.

(57) A metal oxide substrate (e.g. barium strontium titanate **34**) is immersed in a liquid ambient (e.g. 12 molar concentration hydrochloric acid **30**) and illuminated with radiation (e.g. collimated visible/ultraviolet radiation **24**) produced by a radiation source (e.g. a 200 Watt mercury xenon arc lamp **20**). A window **26** which is substantially transparent to the collimated radiation **24** allows the radiated energy to reach the metal oxide substrate **34**. An etch mask **32** may be positioned between the radiation source **20** and the substrate **34**. The metal oxide substrate **34** and liquid ambient **30** are maintained at a nominal temperature (e.g. 25 °C). Without illumination, the metal oxide is not appreciably etched by the liquid ambient. Upon illumination the etch rate is substantially increased.

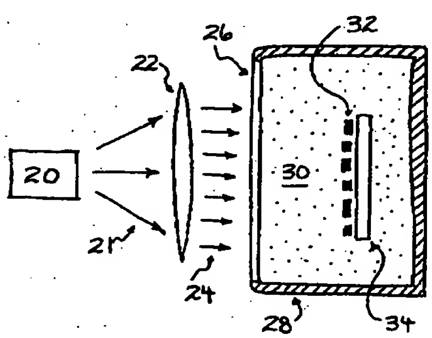

FIG. 1

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Field of the Invention

This invention generally relates to methods of anisotropically etching metal oxide materials.

Background of the Invention

Without limiting the scope of the invention its background is described in connection with current methods of etching metal oxides, as an example.

Metal oxide materials, because of their electrical and mechanical properties, have found many uses in the field of electronics. Examples of these useful metal oxide materials are barium strontium titanate ($BaSrTiO_3$, hereafter referred to as BST), lead zirconate titanate ($PbTiZrO_3$, hereafter referred to as PZT), niobium pentoxide (Nb_2O_5) and tantalum pentoxide (Ta_2O_5). The very high dielectric constants exhibited by many metal oxide compound make them useful as the dielectric material in capacitors especially in the miniature capacitors which are built into many integrated circuits (e.g dynamic RAMs). Many metal oxide materials also have a positive temperature coefficient of electrical resistance, which allows devices to be made which protect electrical motors from damage due to over-current conditions. The piezoelectrical properties of these materials are widely used, as in the precise control of the length of laser cavities, for example. Microminiature structures which incorporate metal oxide materials are being used to sense infrared radiation, obviation the need for bandgap detector materials which require cryogenic cooling to sense the infrared

Metal oxide materials are often etched during the fabrication of the electrical devices which exploit their beneficial properties. A method used to etch metal oxides should generally do so without introducing damage which would unacceptably change the properties of the material on which the function of the eventual devices. In addition, an anisotropic etch method is usually desired so that detail in the etch mask pattern is preserved. Contamination of the metal oxide material (and/or nearby materials) by the etch method usually cannot be tolerated.

Heretofore, in this field, metal oxides have been etched by isotropic wet etching, ion-milling, plasma etching or laser scribing. Laser scribing is a method wherein selected portions of the material are damaged and weakened by exposure to intense laser radiation and then removed.

Summary of the Invention

It has been discovered that current methods of etching metal oxide materials can produce unacceptable results Isotropic wet etching can undercut the etch mask (generally by the same distance as the etch depth), leading to features in the underlying metal oxide material which are not true to the etch mask pattern Ion-milling can generate unacceptable defects in the metal oxide material, including changes in its electrical, chemical, mechanical, optical, and/or magnetic properties. Plasma etching can cause damage similar to that caused by ion-milling, and in addition the plasma constituent elements can contaminate substrate materials and are often difficult to remove. Etching by laser scribing can result in no undercut of the material, but the laser radiation can cause damage to the metal oxide material which must be repaired by a high-temperature (approximately 1400 °C) anneal. This anneal may produce undesirable oxidation states in the metal oxide material, reducing its beneficial properties. High temperature anneals, in addition, can cause changes and damage to other materials and structures present in the substrate.

Generally, and in one form of the invention, etching of a metal oxide substrate is accomplished by immersing it in a liquid ambient and then exposing it to electromagnetic radiation (e.g. ultraviolet light), causing illuminated portions of the substrate to be etched and unilluminated portions to remain substantially unetched. The process presented is therefore an anisotropic liquid phase photochemical etch. In one preferred embodiment, a metal oxide is etched by immersing it in hydrochloric acid and illuminating it with visible and ultraviolet radiation provided by a mercury xenon arc lamp. Hydrofluoric acid may also be used. An etch mask is used to define the pattern of illumination at the surface and thereby define the etch pattern. The highly directional nature of light makes this an anisotropic etch method.

An advantage of the invention is that it anisotropic (i.e does not cause substantial undercut). Those regions under the mask remain in shadow and are not appreciably etched. In addition, it has been found that this method does not cause unacceptable defects in the metal oxide material. Contamination from plasma species is prevented. Generally, no high temperature anneal is required.

Brief Description of the Drawing

The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, as well as other features and advantages thereof, will be best understood by reference to the detailed description which follows, read in conjunction with the accompany drawing.

In the drawing:

FIG. 1 is a representation of the apparatus and materials used to anisotropically etch metal oxide materials.

Detailed Description of the Preferred Embodiments

In the first preferred embodiment of this invention and with reference to Fig. 1, a pattern is etched into a substrate **34** off barium strontium titanate ($BaSrTiO_3$) which is immersed in 12 molar concentration hydrochloric acid (HCl) **30** and illuminated with substantially collimated visible/ultraviolet radiation **24** propagating substantially orthogonal to the substrate surface **34** produced by a 200 Watt mercury xenon arc lamp **20.** Radiation **21** from the radiation source **20** is collimated by collimating optics **22** and the resulting collimated radiation **24** is directed at the substrate **34.** A window **26** which is a portion of the reaction vessel **28** and which is substantially transparent to the collimated radiation allows the radiated energy to reach the BST substrate **34.** An etch mask **32** defines the etched pattern by blocking the radiation at portions of the substrate. The BST substrate **34** and acid solution **30** are nominally at a temperature of 25 °C. At such a temperature and acid concentration and without illumination, BST is not appreciably etched by HCl. Upon illumination by visible/ultraviolet radiation produced by the lamp, however, the etch rate becomes approximately one micron per hour.

The etch mask **32** between the radiation source **20** and the BST substrate **34** is preferably located close to or in contact with the surface to be etched. Such an etch mask **32** may be deposited onto the substrate substrate surface. The etch mask **32** is preferably made of silicon oxide. In general, any substance which is sufficiently opaque to visible and ultra violet light such as that produced by the mercury xenon lamp and which is not substantially penetrated of etched by the liquid ambient may be used, such as silicon oxide or silicon nitride. Noble metals such as platinum may be used. Those areas of the substrate not covered by the mask material will be subject to etching by the acid solution.

In an additional aspect to this embodiment, side wall profile control can be enhanced by introducing a passivating agent into the liquid ambient **30** that does not react with the BST to form a soluble product or only slightly soluble product. The passivating agent "poisons" the sidewalls with respect to attack by other etch reagents on the sidewall, but does not stop etching normal to the substrate because the irradiation detaches the passivating agent from the surface. An example of a passivating agent in an etch of BST is phosphoric acid.

In the second preferred embodiment of this invention and again with reference to Fig.1, a pattern is etched into a substrate **34** of niobium pentoxide (Nb_2O_5) which is immersed in 10% hydrofluoric acid acid (HF) **30** and illuminated with substantially collimated visible/ultraviolet radiation **24** propagating substantially orthogonal to the substrate surface **34** produced by a 200 Watt mercury xenon arc lamp **20**. Radiation **21** from the radiation source **20** is collimated by collimating optics **22** and the resulting collimated radiation **24** is directed at the substrate **34.** A window **26** which is a portion of the reaction vessel **28** and which is substantially transparent to the collimated radiation allows the radiated energy to reach the Nb_2O_5 substrate **34.** An etch mask **32** defines the etched pattern by blocking the radiation at portions of the substrate. The Nb_2O_5 substrate **34** and acid solution **30** are nominally at a temperature of 25 °C. At such a temperature and acid concentration and without illumination, Nb_2O_5 is not appreciably etched. Upon illumination by vsible/ultraviolet radiation produced by the lamp, however, the etch rate is increased. Etch rate ratios as high as 9:1 (illuminated:unilluminated) have been observed.

The etch mask **32** between the radiation source **20** and the Nb_2O_5 substrate **34** is preferably located close to or in contact with the surface to be etched. Such an etch mask **32** may be deposited onto the substrate surface. The etch mask **32** is preferably an organic photoresist. In general, any substance which is sufficiently opaque to visible and ultraviolet light such as that produced by the mercury xenon lamp and which is not substantially penetrated or etched by the liquid ambient may be used. Noble metals such as platinum may be used. Those areas of the substrate not covered by the mask material will be subject to etching.

In an additional aspect to this embodiment, sidewall profile control can be enhanced by introducing a passivating agent into the liquid ambient **30** that does not react with the Nb_2O_5 to form a soluble product or only slightly soluble product. The passivating agent "poisons" the sidewalls with respect to attack by other

etch reagents on the sidewall, but does not stop etching normal to the substrate because the irradiation detaches the passivating agent from the surface. An example of a passivating agent in an etch of Nb_2O_5 is hydrochloric acid.

In the third preferred embodiment of this invention and again with reference to Fig. 1, a pattern is etched into a substrate **34** of tantalum pentoxide (Ta_2O_5) which is immersed in 10% hydrofluoric acid (HF) **30** and illuminated with substantially collimated visible/ultraviolet radiation **24** propagating substantially orthogonal to the substrate surface **34** produced by a 200 Watt mercury xenon arc lamp **20**. Radiation **21** from the radiation source **20** is collimated by collimating optics **22** and the resulting collimated radiation **24** is directed at the substrate **34**. A window **26** which is a portion of the reaction vessel **28** and which is substantially transparent to the collimated radiation allows the radiated energy to reach the Ta_2O_5 substrate **34**. An etch mask **32** defines the etched pattern by blocking the radiation at portions of the substrate. The Ta_2O_5 substrate **34** and acid solution **30** are nominally at a temperature of 25 °C. At such a temperature and acid concentration and without illumination, Ta_2O_5 is not appreciably etched. Upon illumination by visible/ultraviolet radiation produced by the lamp, however, the etch rate is increased. Etch rate ratios as high as 50:1 (illuminated:unilluminated) have been observed.

The etch mask **32** between the radiation source **20** and the Ta_2O_5 substrate **34** is preferably located close to or in contact with the surface to be etched. Such an etch mask **32** may be deposited onto the substrate surface. The etch mask **32** is preferably an organic photoresist. In general, any substance which is sufficiently opaque to visible and ultraviolet light such as that produced by the mercury xenon lamp and which is not substantially penetrated or etched by the liquid ambient may be used. Noble metals such as platinum may be used. Those areas of the substrate not covered by the mask material will be subject to etching.

In an additional aspect to this embodiment, sidewall profile control can be enhanced by introducing a passivating agent into the liquid ambient **30** that does not react with the Ta_2O_5 to form a soluble product or only slightly soluble product. The passivating agent "poisons" the sidewalls with respect to attack by other etch reagents on the sidewall, but does not stop etching normal to the substrate because the irradiation detaches the passivating agent from the surface. An example of a passivating agent in an etch of Ta_2O_5 is hydrochloric acid.

In the fourth preferred embodiment of this invention and with reference to Fig. 1, a pattern is etched into a substrate **34** of lead zirconate titanate ($PbTiZrO_3$ or PZT) which is immersed in 12 molar concentration hydrochloric acid HCl) **30** and illuminated with substantially collimated visible/ultraviolet radiation **24** propagating substantially orthogonal to the substrate surface **34** produced by a 200 Watt mercury xenon arc lamp **20.** Radiation **21** from the radiation source **20** is collimated by collimating optics **22** and the resulting collimated radiation **24** is directed at the substrate **34**. A window **26** which is a portion of the reaction vessel **28** and which is substantially transparent to the collimated radiation allows the radiated energy to reach the PZT substrate **34**. An etch mask **32** defines the etched pattern by blocking the radiation at portions of the substrate. The PZT substrate **34** and acid solution **30** are nominally at a temperature of 25 °C. At such a temperature and acid concentration and without illumination, PZT is not appreciably etched by HCl. Upon illumination by visible/ultraviolet radiation produced by the lamp, however, the etch rate is increased. It is believed, in part because of the relatively low power of the light source, that the etching reaction is accelerated in the illuminated areas because of electronic excitation due to photo-irradiation rather than from thermal effects. As used herein, the term "radiation" means radiation at levels above background and this means, for example, illumination at levels substantially greater than room lighting.

The etch mask **32** between the radiation source **20** and the PZT substrate **34** is preferably located close to or in contact with the surface to be etched. Such an etch mask **32** may be deposited onto the substrate surface. The etch mask **32** is preferably made of silicon oxide. In general, any substance which is sufficiently opaque to visible and ultraviolet light such as that produced by the mercury xenon lamp and which is not substantially penetrated of etched by the liquid ambient may be used, such as silicon oxide or silicon nitride. A noble metal such as platinum may be used. Those areas of the substrate not covered by the mask material will be subject to etching by the acid solution.

In an additional aspect to this method, sidewall profile control can be enhanced by introducing a passivating agent into the liquid ambient **30** that does not react with the material being etched to form a soluble product or only slightly soluble product. The passivating agent "poisons" the sidewalls with respect to attack by other etch reagents on the sidewall, but does not stop etching normal to the substrate because the irradiation detaches the passivating agent from the surface. An example of a passivating agent in an etch of PZT is phosphoric acid.

For all of the preferred embodiments, it is believed, in part because of the relatively low power of the light source, that the etching reaction is accelerated in the illuminated areas because of electronic excitation

due to photo-irradiation rather than from thermal effects. As used herein, the term "radiation" means radiation at levels above background and this means, for example, illumination at levels substantially greater than room lighting.

For all of the preferred embodiments, the liquid ambient may be from the class of solutions that etch the substrate material without light irradiation In tins case, the radiation accelerates the etch rate on illuminated portions of the substrate, resulting in a less isotropic etch. Still other alternate embodiments include liquid ambients containing salts and liquid ambients with pH values less than or equal to seven (i.e. acids and neutral solutions). Still other alternate embodiments include liquid ambients with pH values in the alkaline range (i.e. greater than seven), although neutral and acidic solutions are greatly preferred and have given excellent results as described in the preferred embodiments of this invention.

For all of the preferred embodiments, a pattern may be etched into the surface of the metal oxide material by projecting a patterned light onto the substrate (e.g. by conventional photo-lithographic techniques. Additionally, the liquid ambient may be made to flow with respect to the substrate. The flow rate of the liquid ambient may be varied. The solution temperature can be varied to achieve different etch rates and etch anisotropy. The photon flux may be varied to impact etch directionality and etch rates. The radiation wavelength can be adjusted to achieve different etch directionality and etch rates. The direction of propagation of the radiation need not be normal to the surface The etch solution may be a mixture of species (e.g. one or more passivating agents to enhance anisotropy and one or more reagents to photochemically etch the material.

The sole Table, below, provides an overview of some embodiments and the drawing.

TABLE

Drawing Element	Generic Term	Preferred or Specific Terms	Alternate Terms
20	Radiation Source	200 Watt Mercury/xenon arc lamp	
21	Radiation	Visible/UV light	Radiation which will penetrate the liquid ambient
22	Collimating Optics		
24	Collimated Radiation	Visible/UV light propagating normal to substrate surface	
26	Transparent Window		
28	Reaction Vessel		
30	Liquid Ambient	12 Molar Hydrochloric acid	Other etch constituents such as Hydrofluoric acid (HF); Passivating agents: phosphoric acid; HCl Mixtures of both.
32	Etch Mask	Silicon oxide	Silicon nitride Noble metals such as platinum
34	Metal oxide Substrate	$BaSrTiO_3$ Nb_2O_5 Ta_2O_5 $PbTiZrO_3$	Titanate Compounds such as lanthanum doped lead zirconium titanate. Transition metal oxides such as $LiNbO_3$

A few embodiments have been described in detail hereinabove. It is to be understood that the scope of the invention also comprehends embodiments different from those described, yet within the scope of the claims.

While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. For example, although alkaline solutions are not preferred, they may be the appropriate liquid ambient in some embodiments of this invention. Various modifications and combinations of the illustrative embodiments, as well as other embodiments of the invention, will be apparent to persons skilled in the art upon reference to the description. It is therefore intended that the appended claims encompass any such modifications or embodiments.

Claims

1. A method to anisotropically etch a metal oxide material, said method comprising the steps of
   submersing a surface of said metal oxide material in a liquid ambient; and
   illuminating portions of said surface with radiation, thereby etching said illuminated portions of said surface at a substantially greater rate than the unilluminated portions of said surface.

2. The method according to claim 1, further comprising providing said metal oxide material as a titanate.

3. The method according to claim 2, further comprising providing said titanate as $PbTiZrO_3$.

4. The method according to claim 1, further comprising providing said metal oxide material as barium strontium titanate.

5. The method according to claim 1 to 4, wherein said step of submersing the surface comprises submersing in a liquid ambient of HCl.

6. The method according to claim 5, further comprising providing said HCl as 12 molar HCl.

7. The method according to any of claims 1 to 4, further comprising providing said liquid ambient as phosphoric acid, said phosphoric acid being operable to decrease the etch rate of said unilluminated portions of said surface.

8. A method according to claim 1, further comprising providing said metal oxide as niobium pentoxide.

9. The method according to claim 1, comprising providing said metal oxide as tantalum pentoxide.

10. The method according to claim 8 or claim 9, further comprising providing said liquid ambient as hydrofluoric acid.

11. The method according to claim 10, further comprising providing said hydrofluoric acid as 10% hydrofluoric acid.

12. The method according to any of claim 8 to 11, further comprising providing said liquid ambient as hydrochloric acid, said hydrochloric acid being operable to decrease the etch rate of said unilluminated portions of said surface.

13. The method according to any preceding claim, further comprising providing said liquid ambient as one or more salt solutions.

14. The method according to any preceding claim, further comprising forming said illuminated portions and said unilluminated portions of said surface by a photo-lithographic technique.

15. The method according to any preceding claim, further comprising moving said liquid ambient with respect to said surface.

16. The method according to any preceding claim, further comprising direction said radiation in a direction of propagation substantially orthogonal to said surface.

17. The method according to any preceding claim, further comprising maintaining the temperature of said illuminated portions of said surface at substantially the same temperature as the temperature of said unilluminated portions of said surface.

18. The method according to any preceding claims, further comprising etching said unilluminated portions of said surface with said liquid ambient.

19. An electronic device comprising material fabricated according to the method of any preceding claim.

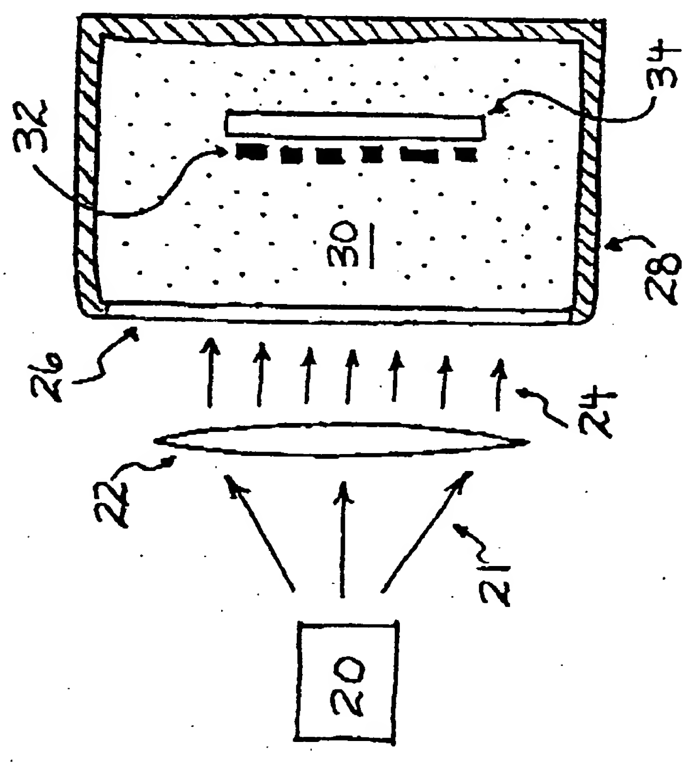

FIG. 1

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20.04.92 US 872702

(43) Date of publication of application:
27.10.93 Bulletin 93/43

(84) Designated Contracting States:
DE FR GB IT

(88) Date of deferred publication of the search report:
09.03.94 Bulletin 94/10

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(54) **Anisotropic metal oxide etch.**

(57) A metal oxide substrate (e.g. barium strontium titanate **34**) is immersed in a liquid ambient (e.g. 12 molar concentration hydrochloric acid **30**) and illuminated with radiation (e.g. collimated visible/ultraviolet radiation **24**) produced by a radiation source (e.g. a 200 Watt mercury xenon arc lamp **20**). A window **26** which is substantially transparent to the collimated radiation **24** allows the radiated energy to reach the metal oxide substrate **34**. An etch mask **32** may be positioned between the radiation source **20** and the substrate **34**. The metal oxide substrate **34** and liquid ambient **30** are maintained at a nominal temperature (e.g. 25 °C). Without illumination, the metal oxide is not appreciably etched by the liquid ambient. Upon illumination the etch rate is substantially increased.

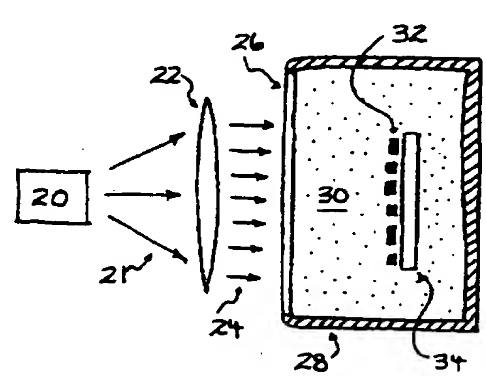

FIG. 1

EP 0 567 063 A3

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EUROPEAN SEARCH REPORT

Application Number
EP 93 10 6374

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	APPLIED PHYSICS LETTERS. vol. 54, no. 13 , 27 March 1989 , NEW YORK US pages 1272 - 1274 HUSSEY ET AL 'Laser-assisted etching of YBa2Cu3O7-delta' * abstract * ---	1,16,19	H01L21/311 H01L41/24 H01L39/24 C04B41/53
X	JAPANESE JOURNAL OF APPLIED PHYSICS, SUPPLEMENT 26-2. vol. 26 , 1987 , TOKYO JA pages 159 - 161 SHIOSAKI ET AL 'Machining of PZT, PT and (Mn, Zn)Fe2O4 ceramics by laser-induced chemical etching' * abstract * ---	1-3,5,6	
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	7 January 1994	Gori, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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A : technological background
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D : document cited in the application
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EUROPEAN SEARCH REPORT

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			TECHNICAL FIELDS SEARCHED (Int.Cl.5)

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EPO FORM 1503 03.82 (P04C01)